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Canada Centre for Mineral and Energy Technology

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Summary Report No. 6: Graphite

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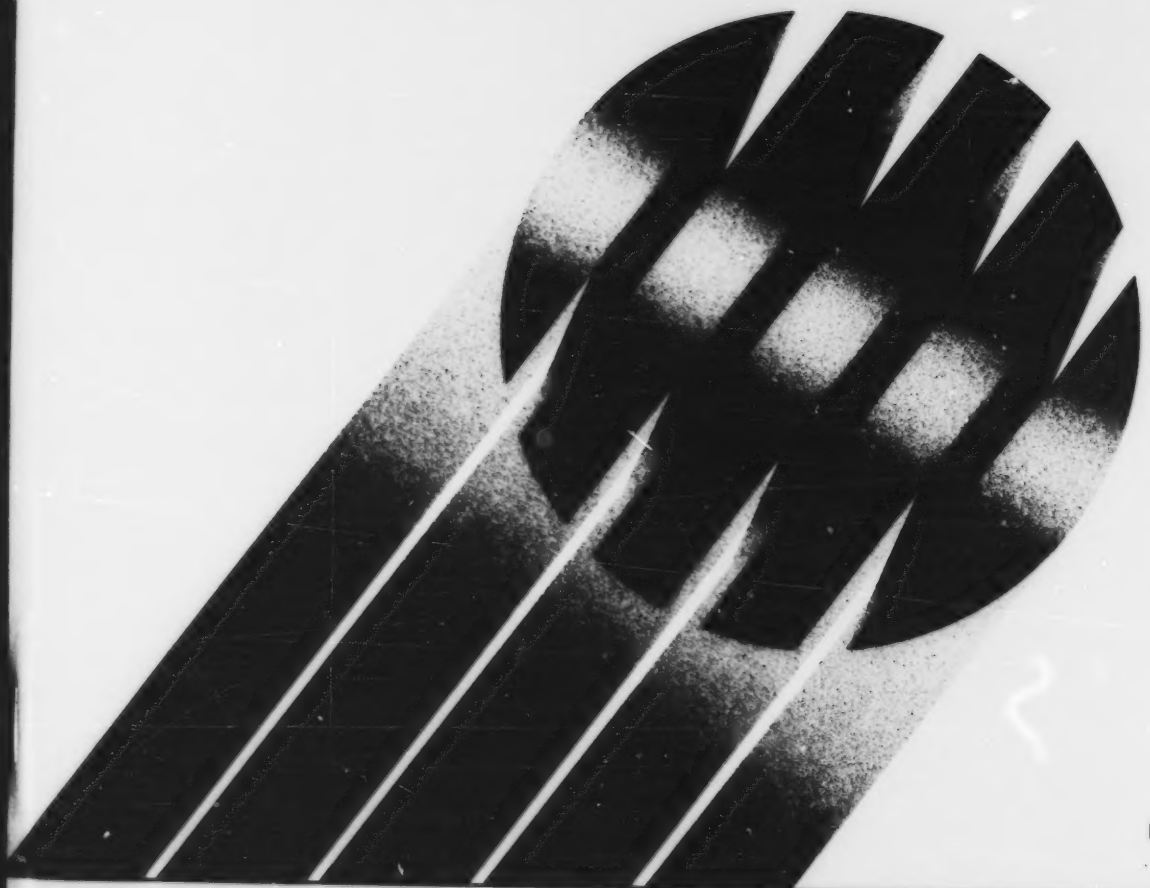
Mineral Processing Laboratory



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SUMMARY REPORT NO. 6: GRAPHITE

R.K. COLLINGS and P.R.A. ANDREWS
Mineral Processing Laboratory

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SUMMARY REPORT NO. 6: GRAPHITE

by

R.K. Collings* and P.R.A. Andrews**

Abstract

Graphite is one of the most versatile of non-metallic minerals because of its diversified properties: it is unctuous, marks readily, burns slowly, is almost chemically inert, is flexible over a large temperature range, and is a good conductor of heat and electricity. Graphite is also hydrophobic, has a negative temperature coefficient of resistivity, has excellent weathering properties, tends to emulsify with water in oil, is readily soluble in molten iron and, after oxidative treatment, can exfoliate like vermiculite. These properties give rise to its major uses in lubrication, refractories, marking instruments, electrical products and paints.

Graphite occurs as three physically distinct varieties: disseminated flake, vein (also called crystalline or plumbago) and amorphous. Flake graphite is the common variety which occurs in Canada. Although graphite occurs in other provinces, the provinces of Ontario and Quebec contain the chief deposits of economic significance.

There are presently two producers of flake graphite in Quebec; Stratmin Inc. and Graphicor Exploration Inc. There are two potential producers in Ontario, both scheduled to begin production in 1990-91; Cal Graphite Corp. and Stewart Lake Resources. Exploration development of graphite deposits in Ontario and Quebec is very active and other producers are expected to come on-stream in the near future.

Graphite ore samples were extensively studied by CANMET between 1929 and 1987. The more important studies are summarized in the Appendix. These summaries comprise information concerning beneficiation (i.e. crushing, grinding, wet tabling and flotation). The flotation parameter data and reagent concentration data are summarized separately.

Keywords: Graphite, production, uses, specifications, beneficiation, CANMET reports.

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RAPPORT SOMMAIRE N° 6 : GRAPHITE

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Résumé

Le graphite est l'un des plus versatiles des minéraux non métalliques, en raison de ses propriétés très diverses : il est onctueux au toucher, laisse facilement une trace, brûle lentement, est presque inerte chimiquement, est flexible sur un vaste intervalle de températures, et est un bon conducteur de la chaleur et de l'électricité. Le graphite est également hydrophobe, présente un coefficient thermique négatif de résistivité, présente d'excellentes propriétés de résistance aux intempéries, tend à former une émulsion avec l'eau dans l'huile, est facilement soluble dans le fer fundu, et après un traitement oxydant, peut s'exfolier comme la vermiculite. Ces propriétés expliquent ses principaux emplois, comme lubrifiant, dans la fabrication de produits réfractaires, d'instruments de traçage, de matériel électrique, et de peintures.

Le graphite se présente sous forme de trois variétés physiquement distinctes : sous forme de lamelles disséminées, de filons (aussi appelés graphite cristallin ou plombagine), et sous forme amorphe. Le graphite lamellaire est la variété la plus souvent rencontrées au Canada. Il existe du graphite dans d'autres provinces, mais les provinces de l'Ontario et du Québec contiennent les principaux gisements d'importance économique.

Il existe actuellement deux producteurs de graphite lamellaire au Québec; la Stratmin Inc. et la Graphicor Exploration Inc. Il existe deux producteurs possibles en Ontario, qui devraient commencer à produire du graphite en 1990–1991; la Cal Graphite Corporation et la Stewart Lake Resources. L'exploration des gisements de graphite de l'Ontario et du Québec se poursuit actuellement de façon très active et les autres producteurs devraient commencer l'exploitation dans un avenir proche.

CANMET a étudié de façon approfondie des échantillons de minerai et de graphite, entre 1929 et 1987. Les plus importantes études sont résumées dans l'Appendice. Ces résumés contiennent l'information sur l'enrichissement (c'est-à-dire le concassage, le broyage, le tablage par voie humide et à la flottation). Les paramètres de la flottation, et les données sur la concentration des réactifs, sont résumés séparément.

Mots clés : graphite, production, utilisations, spécifications, enrichissement, rapports de CANMET.

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INTRODUCTION

A CANMET survey of Canadian industrial mineral producers (1) identified a number of problems specific to the industry as well as potential opportunities for further development and expansion. The response to this survey, and subsequent discussions with industry and government specialists, identified a requirement for information in a number of areas. These areas included mineral deposits, processing, beneficiation studies and new developments, as well as information on product specifications and potential markets for Canadian industrial minerals.

The response to this requirement was a decision to compile related information on file at CANMET and, as available, from provincial government offices and the private sector in a series of *Summary Reports* on a number of industrial minerals. The information for each mineral pertains to mineral occurrences, deposits of specific interest, current activities, product uses and specifications, process technology and summaries of past R&D on specific deposits by CANMET and others. This report, *Summary Report No. 6: Graphite*, is the sixth in the series; the first five being Barite, Celestite, Fluorite, Silica, and Mica and Vermiculite.

MODE OF OCCURRENCE

Graphite is a black, lustrous mineral that is common to many types of igneous, sedimentary and metamorphic rocks. The more important occurrences are those found in metasomatic–hydrothermal deposits and in sedimentary rocks that have been subject to regional or thermal metamorphism. Marble, gneiss and schist are the more common rock types in which economic graphite deposits occur. These occurrences are commonly associated with pegmatite intrusions.

Natural graphite is divided into three general classes: disseminated flake, crystalline vein and amorphous. Flake graphite is a lamellar form found as distinct masses in metamorphic rocks such as marble, gneiss and schist. Crystalline vein graphite occurs as mineralized accumulations in veins associated with pegmatites. Amorphous graphite is a micro crystalline variety commonly associated with coal in slates and shales.

Graffin (2) divides economic deposits of graphite into five main geological types:

1) Flake graphite disseminated in metamorphosed, silica–rich sedimentary rocks;
2) Flake graphite disseminated in marble;
3) Deposits formed by metamorphism of coal or carbon–rich sediments (amorphous);
4) Veins filling fractures, fissures and cavities in country rock; and
5) Contact metasomatic or hydrothermal deposits in metamorphosed, calcareous sedimentary rocks.

Graphite is relatively soft with a hardness of only 1 to 2 on Moh's scale. It has a specific gravity of 2.26 and is an excellent conductor of heat and electricity. Graphite is highly refractory, melting at about 3000°C. It is also very resistant to attack by acids. Flake graphite is opaque, flexible, and possesses perfect basal cleavage.

DEPOSITS

Flake graphite deposits are relatively common in Quebec and Ontario; occurrences are also known in Newfoundland, Nova Scotia, New Brunswick, Saskatchewan and British Columbia. The development of many of these deposits, particularly in Quebec and Ontario which were operated during the period 1850 to 1920, are well chronicled by Spence (3). Deposits of present interest are discussed below and noted on the map, in Figure 1.

Quebec

There are more than 80 graphite deposits of economic interest in Quebec (4), and over 70 of these are located within the Lachute–Hull–Mont Laurier area. They are hosted by highly metamorphosed and deformed rocks belonging to the Grenville Geological Province. Deposits may be divided into lump graphite (vein or graphite–wollastonite) and disseminated flake graphite.

The majority of the economically interesting deposits discovered by traditional prospecting methods between 1845 and 1900 were veins which provided lump graphite of excellent quality. The largest concentration of vein deposits is probably located in the Buckingham area, where veins cut gneisses, marbles and pyroxenites. Some veins are associated with pegmatites. Potential sources of lump graphite also occur as graphite–wollastonite deposits, which are characterized by complex morphology, skarn mineralogy and spatial association with intrusive rocks. Veins or lenses grading from 60 to 99% graphite were reported in some of these deposits. The economic potential of graphite–wollastonite deposits is considered to be higher than that of veins, because wollastonite may be a by–product.

Disseminated flake graphite deposits are hosted by pegmatites, granitic and mafic intrusions, iron formations, quartzites, pyroxenites, marbles and gneisses. Deposits grading over 7% graphite with a large proportion of coarse flakes, and widths that would permit highly mechanized open–cast mining, have the best economic potential. Gneiss–hosted deposits are characterized by larger tonnages, better ore continuity and more constant mineralogy than other graphite deposits. Marble–hosted disseminated flake–graphite deposits are structurally and mineralogically more complex and less continuous than gneiss–hosted deposits.

Asbury Graphite, before ceasing processing because of ore difficulties, obtained ore from a marble–hosted deposit near Notre Dame du Laus, in Papineau County.

Stratmin Graphite Inc., obtains graphite ore from an open pit, marble–hosted deposit, at Lac des Iles near Mont Laurier, and Graphicor Exploration Inc. obtains graphite ore from a deposit north of Buckingham which is hosted by both calcitic and gneissic gangue minerals.

Deposits under current investigation include Lac Knife and Lac Corbeil near Fermont.

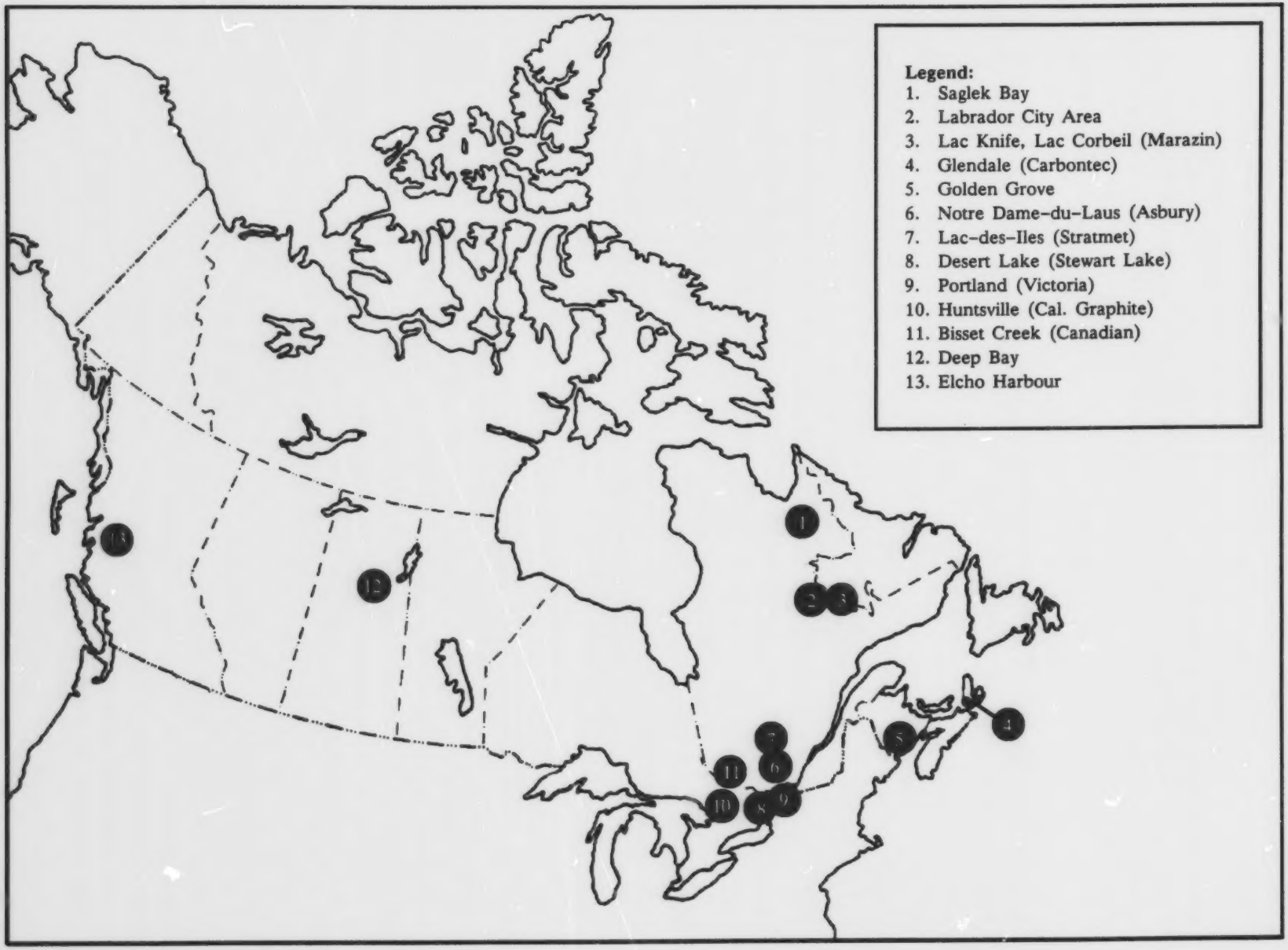

Figure 1 - Principal Graphite Deposits in Canada

Ontario

Numerous graphite occurrences have been recorded in the Grenville Geological Province in south eastern Ontario by Hewitt (5), Papertzian and Kingston (6). Papertzian and Kingston report fifty-four deposits, occurrences, prospects, and past producers; eighteen of these were examined, of which eight were judged to have significant unexplored development potential. These were identified as the Beidelman-Lyall, Carter Lake, Kirkham, Bowden, Timmins, Cornell, Globe and Butt Township deposits, which are all flake deposits of the metasomatic or hydrothermal type. Ontario does not have any known metamorphosed coal-associated deposits, and all known vein-type deposits are too small and irregular to warrant development.

The largest producer of flake graphite in Canada was the Black Donald mine near Calabogie. This mine operated during the period 1896 to 1954 and produced in excess of 86,350 t of graphite concentrates from feed ore analyzing 65% C.

Deposits under current study include Huntsville, Desert Lake, Portland and Bissett Creek, all in south-eastern Ontario.

Newfoundland

Graphite occurrences in Newfoundland are numerous, however Meyer (7) reports that most are of the amorphous variety being associated with shales, slates, schists and breccias and, therefore, are of minor economic interest. Meyer also notes two areas of interest in Labrador. The first in western Labrador, in the vicinity of Labrador City, where an occurrence of disseminated graphite and bands of graphite are located in impure quartzites, marbles and gneisses. The second is at the end of Saglek Bay in northern Labrador where graphite occurs as individual lenses and disseminated flakes in garnet-biotite gneisses.

Nova Scotia

Amorphous graphite occurrences are recorded at a number of locations in Nova Scotia but most are of little economic interest. One deposit, located about 3 km north-west of Glendale, Cape Breton Island, was extensively explored by trenching and shaft sinking during the early 1930's. The graphite associated with shale and slate occurs in a 16 to 32 m-wide zone that is traceable over a distance of 320 m. Trench and shaft samples taken at that time analyzed 40 to 60% C (8).

New Brunswick

Graphite occurrences in New Brunswick are mostly narrow vein-type deposits associated with fault or shear zones in limestone. Deposits near Split Rock and Marble Cove were worked during the early part of the century but are of little current interest (9). The Golden Grove deposit, located northeast of St. John, was drilled in early 1987. A twenty-two hole diamond drill programme, totalling about 3,300 m, identified two significant en echelon graphite zones in a deposit that is steeply dipping and

open at depth. Petographic examination of samples by the RPC in Fredericton indicated that 90% of the graphite occurred as fine flakes. There has been no development since 1987 (10).

Saskatchewan

A number of occurrences of graphite have been recorded in the north-eastern portion of the province but only one occurrence, near the south-western shore of Deep Bay, Reindeer Lake, has been evaluated for development. The Deep Bay graphite occurs in a coarse-grained, biotite-gneiss; the mineralized area reportedly is several kilometres long. An ore zone up to 46 m wide by 580 m long was outlined with open pit reserves of 1.6 Mt to a depth of 65 m. The average grade is about 10% C (11).

British Columbia

Twenty-four occurrences of graphite have been recorded in the province but most are small and of no commercial interest. A large deposit of disseminated graphite occurs at Elcho Harbour on the south shore of Dean Canal. The graphite content of this deposit reportedly is about 20% C; no estimates of reserves are available (12).

TECHNOLOGY

Mining

Graphite deposits are usually located at or near the surface and are typically mined by open-pit methods. Underground mining methods are only employed when warranted by grade and structure. The present graphite producers operate open-pit deposits. Underground mining of graphite was relatively common in eastern Ontario and in the Buckingham area of Quebec during the early 1900's with shafts extending to depths of 80 m or more.

The planned production of graphite from the Stewart Lake property will be by open-pit quarry for the first 2.5 years, and by underground operation for the following 9 years (13).

Processing and Beneficiation

Flake graphite in Canada is too finely disseminated for hand sorting and cobbing methods, which are used in some countries to recover massive-flake graphite. Production of Canadian graphite is usually only possible by a combination of careful grinding and screening to recover coarse flakes, and flotation to recover fine flake. Flotation concentrates are sometimes further beneficiated by tabling to

remove associated gangue minerals such as quartz, mica, hornblende, feldspar, calcite and base metal sulphides. Impurities tend to float with graphite since, being soft, graphite tends to smear and coat impurity minerals during grinding so that they behave like graphite. This is especially true when processing finely divided ores that require extensive grinding.

Size reduction is usually accomplished by jaw, cone, or hammer mill–type crushers; screening to recover coarse flakes or reject coarse hard impurities is accomplished by trommel or vibratory screens. The recovery of intermediate and fine–flake graphite is possible by rolls crushing, ball, roller or jet milling followed by additional screening, air classification, wet tabling or flotation.

Graphite is naturally floatable and particles as coarse as 1 mm may be floated in a slightly alkaline pH medium. Pine oil and kerosene are the standard collectors and are usually employed together. The alcohol frother is the primary collector, and the function of kerosene or fuel oil is as a promoter to recover unliberated graphite middlings. Flotation is fairly fast, and multiple cleaning is necessary for the recovery of high–grade concentrates. Graphite concentrates typically grade 85 to 90% C with recoveries of 80 to 85%. Recovery can be improved by regrinding and reflotation, but careful regrinding is necessary to avoid smearing of gangue minerals and the production of slime graphite.

Modifiers and depressants to improve selectivity include sodium silicate which acts as a quartz depressant and slime dispersant, and lactic acid, $C_3H_6O_3$, which is used to depress mica.

Graphite may be further purified to 99% C by chemical treatment, chloridization or fluoridization. A product containing 99.8 to 99.9% C was obtained by treating concentrates with 25% caustic soda at 150°C in an autoclave at 5.5 atm. The residue was washed in a centrifuge and treated with boiling 20% HCl for 30 min. (14).

USES AND SPECIFICATIONS

Graphite is used in a variety of applications by virtue of its inherent physical and chemical properties. These properties include a low coefficient of friction, chemical resistance and stability over a wide range of temperatures, increased strength with rising temperatures, a high melting point (3650°C), high thermal and electrical conductivities, and a low absorption co–efficient for neutrons and X–rays.

The metallurgical industry is the chief consumer; graphite in various forms is used in the manufacture of crucibles, retorts, moulds, ladles and refractory brick for foundry–mould facings. Miscellaneous metallurgical applications include carbonizing steel, as a top insulator for molten metal, and in electrode manufacture. The non–metallurgical graphite applications, which are almost as diverse, include the manufacture of brake linings, and brushes for electrical motors. Other important applications include paint, explosives, lubricants, and as a neutron moderator and reflector in nuclear power plants.

Natural graphite is less expensive than manufactured or synthetic graphite and is used in many applications. Synthetic graphite is used where high purity is essential, as in the manufacture of electrodes.

The various uses and specifications for natural and synthetic graphite are described in some detail in the following sections, and are summarized in Table 1.

Natural Graphite (14–18)

Crucibles, Moulds and Ladles

Flake graphite mixed with refractory clay and quartz sand is used in the manufacture of crucibles, moulds and ladles used by the steel, non–ferrous and precious metals industries. The graphite content of the mix varies widely and usually represents from 10 to 90% of the total weight. The ingredients are finely ground to about 350 μm before mixing, forming and firing. A high–purity graphite containing 85 to 95% C is preferred. Impurities such as iron oxide, iron sulphide, mica, carbonaceous and other fusible minerals should be low as they either fuse or decompose on heating to form small cavities in the crucible, or mould, which weaken the structure.

Refractory Brick

Flake, crystalline and microcrystalline graphite are used in the manufacture of resin–bonded, magnesia–carbon (mag–carbon) brick. The carbon content varies but may be as high as 20 to 25%. Mag–carbon brick is resistant to deterioration at high temperatures, so that it is commonly used in linings for steel and iron furnaces, for slag–lines, ladles and nozzles. Graphite for this application should be 85 to 95% C, and be 100 to 500 μm in size. Impurities such as silica, alumina and iron are detrimental as they form low melting compounds that decrease both the strength and life of the refractories.

Foundry Facings

Finely ground flake or amorphous graphite mixed with refractory clay is used as a foundry facing or coating for moulds to provide a smooth finish to castings and to facilitate release of the casting from the mould on cooling. Talc, silica sand and mica are sometimes added to the facing mix to improve its properties. Graphite used for this purpose need not be of exceptional purity, 40 to 70% graphite is sufficient. Sulphides and readily fusible minerals are deleterious and should be at a minimum. Particle size should be between 50 and 75 μm.

Brake Linings

High–grade crystalline graphite analyzing 98% C and 75 μm in size is used in motor vehicle brake and clutch linings to help reduce the rate of wear. Abrasive minerals such as quartz and feldspar should be absent.

Table 1. Uses and specifications for graphite (20)

Application	Average % C content	Average flake size µm	Comments
Foundries			
– amorphous	40 to 70	50 to 75	Sulphides deleterious, quartz and mica advantageous.
Crucibles	80 to 90	+ 150	Primarily large crystalline flakes, but size varies; typically 75% +600 µm, 75% +400 µm or 75% +300 µm.
Refractory bricks			
– amorphous	70 to 80	–20 mm and –600	
– flake (higher quality bricks)	90 to 97	+180 to +150 (sometimes to +75)	Over the last few years a trend has developed toward using finer sizes as well as higher carbon materials.
Magnesia–carbon bricks	min 85 optimum 87 to 90	+150 to –710	Flake graphite with a preferred aspect ratio of 20:1 is used; ash content should be <2%, but up to 10% is tolerated.
Alumina graphite refractories	min 85	–600 to +150	
Expandable graphite	min 90	–1700 to +250	
Brake linings	min 98	–75	Blends of 60:40 (natural, synthetic).
Batteries	min 88	85% – 75	Usually ground natural graphite.
– dry cell	min 98	–75 to 5	Pure natural graphite or synthetic with no
– alkaline			impurities such as Cu, Co, Sb, As.
Brushes	95 to 99	ground to about –50	Usually 99% C as application cannot tolerate more than 1% silica and ash impurity.
Sintering	98 to 99	5	Can be natural or synthetic.
Lubricants	98 to 99	–100 +50	
Conductive coatings (amorphous)	50 to 55		May contain 20–25% silica.
Core and mould washes			
– flake	80 to 90	75	
– amorphous	70 to 80	75	

Paint

A mixture of 50 to 55% finely ground amorphous carbon and 20 to 25% silica is used in the manufacture of specialty paints for use on metal surfaces exposed to corrosive conditions. Deleterious minerals which should be kept to a minimum are pyrite, which forms sulphuric acid on weathering, and mica, which may cause flaking of the paint.

Explosives

Amorphous carbon, finely ground to minus 150 μm, is used in the manufacture of explosives as a coating on individual grains of powder to control the burning or explosive rate. The graphite also reduces friction between the powder grains which, in turn, reduces the danger of pre-ignition. Graphite used for this purpose should be free of sulphides and moisture which may promote the formation of sulphuric acid.

Lubricants

Graphite is an excellent lubricating agent and is incorporated in piston rings and bearings to reduce friction and heat build-up. Fine-ground 50 to 75 μm graphite is emulsified (5 to 10%) in oil, grease or water for use in lubricating moving machinery parts. Abrasive impurities such as quartz and feldspar should be absent or present in trace amounts. Metal sulphides or free sulphur are deleterious as they may form sulphuric acid. Mica and other soft minerals can, however, be tolerated in small amounts.

Miscellaneous

Minor quantities of natural graphite are used in the manufacture of lead for pencils, as an ingredient in drilling muds, and as an additive in rubber.

Synthetic Graphite (19)

Synthetic or manufactured graphite is made from a mixture of petroleum coke or anthracite filler, coal tar or petroleum pitch binder, and various impregnating or additive materials. The coke or anthracite, which should contain 95% C and have a low sulphur content, is calcined to remove volatiles, ground, mixed with binder and other materials, and moulded to the required shape. The product, known in the trade as 'green bar' or 'green stock', is then baked at 800 to 1000°C to convert the pitch binder to coke and to solidify the shape. The resulting product is then 'graphitized' by heating in an electric furnace at 2600 to 3000°C over an extended period. The product is then cooled and machined to final size specifications.

Electrodes

Synthetic graphite is used in the manufacture of electrodes for electric arc furnaces for the production of steel, aluminum, copper, magnesium and other metals and alloys. Electrode manufacture is by far the largest use for synthetic graphite.

Moderator and Reflector

Finely ground synthetic graphite, pressed and moulded into required shapes, is used in nuclear reactors to slow down (moderate) and contain (reflect) neutrons produced during the nuclear fission process. An extremely pure product is required for this purpose, and neutron-absorbing elements such as boron and rare earths should be absent or present only in trace concentrations. Natural graphite concentrated by mineral processing and purified by chemical treatment has been utilized for this purpose in Germany. The ash content was less than 0.04%, and the concentration of rare earths and boron less than 1 ppm.

Miscellaneous

Synthetic graphite is used in the aerospace industry for the manufacture of rocket nozzles, nose cones and leading edges for wings. Other uses include recarbonizing steel, the production of graphite fibre for reinforcing plastics, and the manufacture of certain sports equipment e.g., golf clubs, tennis rackets and skis.

Natural/Synthetic Graphite (14, 19)

Carbon Brushes

Natural or artificial graphite for this application is finely ground, mixed with coke, carbon black and a coal-tar pitch or thermal setting resin, compressed, and heat-treated to form blocks. These blocks are cut to size and machined to form brushes for use in electric motors. A low silica, non-abrasive, high-grade amorphous graphite grading >95% C is preferred, and particle size should be 150 μm.

Batteries

Natural or artificial graphite is used in the manufacture of dry-cell batteries because of its inherent high electrical conductivity. The graphite should be high grade, 85 to 90% C, and size should be generally minus 100 μm. Alkaline batteries require a higher purity graphite that should be at least 98% C. The graphite should be free of metallic impurities (conductors) such as copper, nickel, cobalt and antimony; sulphur should not exceed 0.5%.

Exfoliated Graphite

Exfoliated graphite is increasingly being used as an insulating agent in the casting of steel, and as a hot topping material or exothermic powder to cover ingots to lessen heat loss. The expandable process, originally developed by Dow Chemicals, involves a two-stage treatment of crystalline graphite, which involves oxidization by chromic acid followed by the addition of dilute sulphuric acid. The sulphuric acid acts as a secondary oxidizing agent, and as a carrier for water which is deposited between the graphite layers. Following washing to remove acid, the graphite is rapidly heated. Heating produces an expansion of 100 to 500% of the original volume.

Graphite for use in this application should be at least 85% C and be ground to a size range of minus 2 mm to 250 μm.

CURRENT PRODUCERS

Stratmin Inc.

Asbury Graphite Quebec Inc., a subsidiary of Asbury Carbon Inc. of the United States, was Canada's only graphite producer between July 1980 and March 1989. Production ceased, however, when ore difficulties were encountered. Asbury operated an open-pit mine on an intermittent basis at Notre-Dame-du-Laus, about 65 km north of Buckingham. The graphite, which graded 8% C, occurred as disseminated flakes in crystalline limestone associated with quartzite and biotite.

A drilling programme in 1988 indicated an economic graphitic deposit at the Lac-des-Iles property near Mont Laurier with ore reserves estimated at 24 Mt grading 7.5% C. An agreement was reached between Stratmin Inc. and Asbury Graphite Quebec Inc. to process the Stratmin ore at Asbury's milling facilities, and production at the rate of 400 t.p.a. commenced in February 1989. Estimated rate of production of >92% C concentrates is 10,000 t.p.a.

The concentrates will be sold to the parent company Asbury Carbon Inc. and to C. ITOH Ceramics Corp. of Japan.

Concurrent with the processing of ore in the Asbury concentrator, Stratmin commenced construction of its own mill on the Mont Laurier property. The new mill will allow Stratmin to triple the current 500 t.p.d. processing rate of graphite ore to 1400 t.p.d., which will result in the production of 30,000 t.p.a. of graphite concentrates (21).

The ore is size-reduced by a combination of autogenous grinding, rod and slug milling, followed by wet tabling and flotation to produce various sized products (22):

plus 300µm, analyzing 93 to 96% C
minus 300µm plus 150µm, analyzing 90 to 96% C
minus 150µm, analyzing 94 to 98% C

Graphicor Exploration Inc.

Quebec's second producer, Graphicor Exploration Inc., began operations in May 1990. The graphite occurs north of Buckingham, near Montebello, in an area which exhibits numerous small deposits, all between two and three million tonnes, and grading about 9% C after dilution.

The host mineralogy is extremely variable, varying from calcitic to gneissic. The beneficiation of graphite from such diverse mineralogical origins required a concentrator design that was both simple to operate and versatile enough to accommodate ore variability.

The Centre de Recherches Minérales, Québec, assisted the company with metallurgical testwork, design, planning and graphite characterization. The resulting flowsheet, shown in Figure 2, is an all flotation and screening operation. The concentrator is characterized by a vertical design to accommodate the large flotation columns and screening operations. The mill is designed for unit mobility, so that when one deposit is mined out, the mill can be moved to the next site.

The mill design is based on a 2m rougher column and four 1m cleaner columns. The proposed treatment rate is 40 t.p.h. of graphite ore to produce an estimated 20,000 t.p.a. of graphite concentrates (23).

POTENTIAL PRODUCERS

Cal Graphite Corp.

A production feasibility study, prepared in late 1986 for Cal Graphite Corp. of Lively, Ontario, indicated an economic graphite deposit at Graphite Lake near Huntsville in Butt Township. An initial estimate of proven and probable reserves was 29 Mt grading between 2.5 and 3.5% C. A more recent summary of exploration results suggests that proven and probable reserves are between 50 and 60 Mt grading 2.42% C (24).

The main deposit has an average thickness of 50m and extends below the surface for at least 300m. The host rock is sedimentary in origin, and lies within the Central Gneiss Belt, an integral part of the Grenville Province (25).

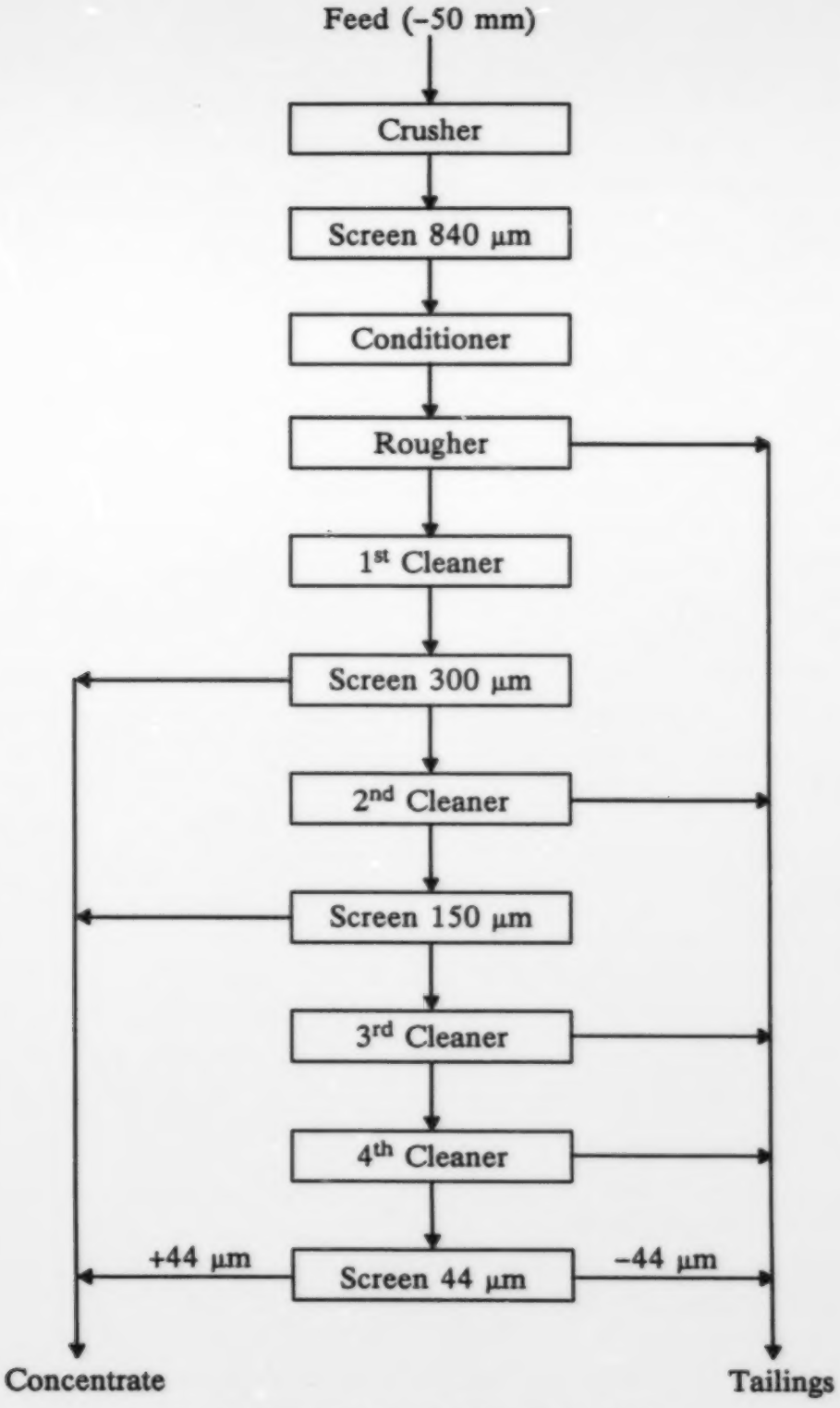

Fig. 2 – Graphicor Processing Circuit Flowsheet

A 4,500 t.p.d. processing facility has been constructed and operations are scheduled to begin in June 1990. A contractor will mine and crush the ore to minus 50mm for about 9 months of the year. A stockpile of coarse ore will be built up to allow year-round processing in the concentrator.

The coarse ore will be further crushed to minus 840 µm using a Barmac Duopactor rotary autogenous crusher. Coarse-flake graphite will be recovered by column flotation in conjunction with regrinding and reflotation in four vertical flotation columns followed by drying and screening. The initial processing target is 3000 t.p.d., and 80% of the production, grading 94% C, will be sold in various particle sizes for established uses. The remaining 20% of production will be further processed at the company's refinery and research plant at Sudbury to a purity of up to 99.97% by hot pressure leaching (25-27).

Stewart Lake Resources Inc.

The Kirkham crystalline flake graphite property of Stewart Lake Resources is located near Godfrey, about 40 km north of Kingston, Ontario. Stewart Lake Resources has, since 1987, spent over $5M on geological, mining and metallurgical studies. This work identified reserves of 927,400 t of crystalline flake graphite grading 8.61% C. Excellent potential exists along strike and down dip of the main ore zones for expanding these reserves and there are, in addition, other as yet unexplored graphitic zones (13).

A pre-feasibility study, prepared by Kilborn Engineering in 1988, indicated that underground mining of 300 t.p.d. of high-grade ore could sustain a processing operation to produce 12,000 to 14,000 t.p.a. of graphite concentrates. The proposed processing rate of 87,000 t.p.a., based on present ore reserves, will ensure about 12 years production. A quarry operation will provide mill feed for the first 2.5 years followed by 9 years of underground mining.

Stewart Lake Resources Inc. is presently proceeding with rezoning and permit applications, and is predicting a production target for late 1990 or early 1991. The processing of graphite will involve crushing, single-stage fully autogenous grinding, and column flotation followed by screening to produce plus 300 µm, minus 300 µm plus 150 µm, and minus 150 µm size products (13).

Marazin Exploration Inc.

Exploration work began in 1986 on the Lac Knife deposit which is located 35 km south of Fermont on the Quebec-Labrador border. The graphite-rich zone extends over 150 m and has a surface width of between 20 and 40 m (28).

This deposit, which consists of three zones, is situated in a fine-to-medium grained quartz-feldspathic-biotite gneiss. Sulphides, mainly pyrrhotite and a lesser amount of pyrite, represent 5 to 20% of the rock. Sphalerite represents 2% and carbonates 5% of the total. Accessory minerals include garnet, kyanite, magnetite and muscovite. Total reserves (proven, probable and possible) are estimated to be 8.75 Mt grading 14.2% C (29).

Construction of open-pit mining installations is scheduled to begin in mid-1990 and operational start-up is intended for mid-1991. The projected processing rate is 400 t.p.d. yielding 23 000 t annually of graphite concentrates. The estimated mine life is 67 years.

Princeton Resources Corp.

Princeton Resources Corp. and North Coast Industries Ltd. are joint partners in the Bisset Creek crystalline flake graphite deposit. The deposit, which is 300 km northeast of Toronto, consists of three separate mineralized zones, each with disseminated graphite flake at various depths from the surface to 85 m. The estimated ore reserves are 34 Mt grading 3.3% with a 2% cut-off. The graphite is hosted in a biotite gneiss.

Laboratory testwork undertaken by Lakefield Research in 1986 successfully produced 420 μm, 210 μm, and 150 μm flake graphite by a combination of crushing, grinding and flotation. The cleaned concentrate, evaluated by ignition loss analysis, averaged 84.5% C (30).

A 200 t.p.d. pilot plant was constructed and operated between November 1986 and May 1987 when 30 t of quality crystalline flake graphite concentrate was produced for product evaluation (31).

A pre-feasibility report prepared by KHD Canada Inc. indicated that high-grade graphite concentrates could be prepared from the ore. Concentrate analyses were from 90 to 92% C and it was also indicated that over 50% of the material has a grain size between 1.2 mm and 300 μm. Further upgrading by acid leaching produced a grade of 98 to 99% C. It is proposed that mining will be by open-pit and that the concentrator will produce 16,900 t.p.a. of graphite concentrates. At an annual processing rate of 600,000 t.p.a. of ore, the estimated mine life is 25 years (20).

CURRENT INTEREST

Several companies are active in the exploration for graphite and the evaluation and development of deposits. These include Victoria Graphite Inc. and Lodi-Black Hawk Inc. in Ontario; Carbontec Industries Inc. in Nova Scotia, and Exploration Brex in Quebec.

Victoria Graphite Inc.

Victoria Graphite recently completed a drilling and trenching programme on graphite deposits located near Portland, Ontario. The indicated reserves (all categories) are 295,000 t grading 6% C. These reserves could sustain a mine for 10 years at a processing rate of 100 t.p.d.

Drill core from the property is undergoing metallurgical testing, and an existing mill is being refurbished and equipped for future full-scale production (32).

Lodi–Black Hawk Inc.

A graphite deposit in the Timmins area, northern Ontario, is currently under evaluation. Trenching and surface work has been conducted but no bulk sampling is as yet reported (20).

A deposit near Perth, Ontario has similarly been trenched and surface sampled, and reserves (all categories) are estimated at 1Mt grading 8% C (33).

Carbontec Industries Inc.

Carbontec was founded in December 1985 to investigate a graphite deposit located on Cape Breton Island, Nova Scotia. The deposit is a large schistose body with a graphitic content of 25 to 70% C, which mainly consists of amorphous graphite but with some crystalline flake. The company intends to produce a high-grade, 90% plus graphite product (20).

Exploration Brex

Exploration Brex, Quebec acquired an option agreement in 1989 to explore a graphite property in Preston Twp. about 20 km from Mont Laurier, Quebec. Preliminary sampling has produced grades up to 12% C, and tests on ground material indicate that most of the graphite is present in flakes larger than 425 μm. An exploration programme designed to trace the graphite-bearing horizon and provide samples for metallurgical evaluation, is presently being conducted (34).

PRODUCTION, TRADE AND CONSUMPTION (35)

Imports of crude graphite for 1988 were valued at $3.07 M. Consumption (1987) was reported at 14,403 t, and was mostly used as foundry facing by the metallurgical and refractories industries. Imports of crude graphite and graphite-related products for 1988 are reported in Table 2, and consumption of graphite in Canada for 1986-87 in Table 3.

Table 2. Imports of crude graphite and graphite-related products

	1988 (tonnes)	1988 ($000)
Natural graphite in powder or flake		
- United States	3,210	2,609
- Switzerland	67	337
- West Germany	55	49
- Other countries	49	72
Total	3,381	3,067
Refractory bricks, etc. n.e.s., (containing by weight more than 50% carbon or graphite)		
- United States	185,586	36,762
- West Germany	4,718	3,418
- Japan	2,291	4,722
- United Kingdom	1,330	1,609
- Other countries	4,503	606
Total	198,428	47,117
Refractory ceramic goods, n.e.s., more than 50% of graphite or other forms of carbon, etc. (including crucibles)		
- United States	-	1,527
- United Kingdom	-	269
- France	-	210
- Other countries	-	388
Total		2,394
Carbon or graphite brushes		
- United States	391	3,121
- West Germany	11	153
- Japan	11	109
- Other countries	3	37
Total	416	3,420

Source: Statistics Canada

- Not available

n.e.s.: Not elsewhere specified.

Table 3. Reported consumption of graphite in Canada

	1986	1987
Reported consumption[1] of graphite		
- Foundry facing	10,294	10,003
- Ferroalloys and primary steel	795	950
- Refractories	757	740
- Other[2]	1,911	2,710
Total	13,757	14,403

[1] Reported from EMR survey on the consumption of non-metallic minerals by Canadian manufacturing plants.

[2] Includes brake linings, chemicals, abrasives, batteries and other end-uses.

Prices*

Graphite is marketed as lump, flake or powder; current prices for typical products are as follows:

Crystalline lump, 92/99% C	U.S. $ 750-1,500
Crystalline large flake, 85/90% C	820-1,300
Crystalline medium flake, 85/90% C	770-1,120
Crystalline small flake, 80/95% C	540 - 900
Powder (75μm) 80/85% C	325 - 360
90/92% C	520 - 600
95/97% C	770-1,000
97/99% C	1,000-1,300
Amorphous powder, 80/85% C	220 - 440

CANMET STUDIES

Background

Twenty-eight CANMET and Mines Branch studies relating to various aspects of graphite beneficiation, and five studies by other organizations were reviewed. A summary of each CANMET study is presented in Appendix 1, and a summary of each study by other organizations in Appendix 2. The title, report number, authors' names, and a summary of work and results are included.

*Prices as reported in the Industrial Minerals Magazine

The summary of each study generally includes the original sample weight, head analysis, mineralogy, beneficiation methods, beneficiation product sizes, concentrate grades and recoveries, and remarks or observations of particular interest. The original sample weight is indicative of the scale of investigation, whether bench, laboratory, semi-pilot plant or pilot plant. The head analyses provide data concerning the mineral content and whether the sample was from a high-grade or low-grade deposit. Mineralogical information not only identifies major and minor minerals, but also provides data regarding association between minerals and host rocks. In many cases, the liberation size is either not known or not stated; however, the beneficiation product size is quoted since, by inference, product size under optimum test conditions usually equates to liberation size. Beneficiation methods are important as a guide for future studies of ores with similar mineral assemblages, and concentrate grade and recovery figures provide an indication of how efficient the beneficiation methods were in achieving a specification product. Additional data regarding flotation parameter and reagent concentration are also reported.

When possible, all studies common to a particular deposit are grouped together for continuity and convenience of reference.

The noted thirty-three graphite studies were conducted between 1927 and 1989. Most studies were conducted on samples from Quebec and Ontario; two were on samples from New Brunswick, one on a sample from British Columbia, and one on a sample from Labrador. A summary of process data for all graphite ores is reported in Table 4, and a summary of analytical data for all graphite ores is reported in Table 5.

Scale

Most studies were conducted on feed material weighing less than 150 kg; seven studies (39,40,41,51,53,60,61) were concerned with ore weighing 250 kg or more. Two non-CANMET ore samples, the first, involving 100 t and the second, 225 t, were processed through the former Black Donald concentrator (65,66).

Head Analyses

The graphite content of the samples varied widely, from 3.1% C for a siliceous graphite ore from Low, Quebec (46), to 68.0% C for a siliceous graphite ore from Bonthellier, Quebec (48). The majority of ores generally contained less than 25% C.

Analysis of Graphite

The analysis of graphite can be subject to variation depending on the minerals associated with a particular ore. The carbon content of acid soluble carbonaceous minerals such as limestone or dolomite are determined first by acid dissolution. Graphitic carbon is then determined by loss on ignition at 800 to 850° C using a combustion time of between 30 and 45 min.

Table 4. Summary of beneficiation studies of graphite: process data

Deposit location	Sample No.	Sample wt (kg)	Product sizes	Process methods	Reference
Labrador					
Wabush	1	10	+300 μm; +150 μm; +100 μm; +70 μm −70 μm	grinding, wet and dry screening, flotation	36
New Brunswick					
St. John area	2	136	−850 μm	grinding, flotation, tabling,	37
St. John area	1	n.s.	−150 μm	dry grinding, flotation	38
Quebec					
Buckingham	1	4.5*	+180 μm; −180 μm	flotation	39
Buckingham	1	16.9*	+710 μm; −710 μm	grinding, screening, tabling, flotation, tabling	40
Guenette	1	12.8*	+710 μm; −710 μm	grinding, screening, tabling, flotation, tabling	41
Lochaber	1	24	+210 μm; +125 μm; +100 μm; −100 μm	flotation, sizing	42
Lochaber	1	9	+210 μm; +125 μm; +100 μm; −100 μm	flotation, sizing	43
Buckingham	1	32	+210 μm; +125 μm	flotation, tabling, sizing	44
Wentworth	1	50	25 μm; −125 μm +3.4 mm;	crushing, screening	45
Low	1	36	−3.4 +1.2 mm;	grinding, flotation	46
	2	23	−1.2 mm +600 μm	grinding, flotation	
Temiskaming	1	11	−1.7 mm	grinding, flotation	47
Bonthellier	1	59	−1.7 mm	grinding, flotation	48
Dun Raven	1	91	−210 μm −600 μm +1.7 mm; −1.7 mm +600 μm; −850 +600 μm	crushing, screening, vanning, magnetic separation, tabling, flotation	49

n.s. – not stated
*tonnes

Table 4. (Cont'd)

Deposit location	Sample No.	Sample wt (kg)	Product sizes	Process methods	Reference
Quebec (Cont'd)					
Mont Laurier	1	n.s.	−50 + 25 mm; −1.2 mm +75 μm	crushing, screening, flotation	50
Gatineau	1	360	−25 + 4.8 mm; −2.4 mm; −1.2 mm +600 μm; −1.2 mm	crushing, screening, air tabling, electrostatic separation, flotation, screening	51
Mont Laurier	1	136	+75 mm; −25 + 2.4 mm; −2.4 mm; −1.2 mm +150 μm; −600 μm	autogenous grinding, autogenous grinding flotation, air tabling, magnetic separation	52
Ontario					
Griffith	1	272	−600 μm	grinding, flotation, screening	53
Fort Frances	2	3	+210 μm; +125 μm; −125 μm	grinding, flotation, tabling, screening	54
	3	9	+210 μm; +125 μm; −125 μm	grinding, flotation, tabling, screening	
Lyndoch	1	18	40% +210 μm	flotation, leaching	55
Bancroft	1	24	54% − 75 μm	grinding, flotation	56
	3	44	54% −75 μm	grinding, flotation	
Lyndoch	1	13	−300 μm	dry grinding, flotation	57
Lyndoch	1	13	77% −75 μm	grinding, flotation	58
Perth	1	109	−4.8 mm; −1.7 mm +44 μm	differential grinding, sizing, flotation	59
Niagara Falls	1	4.6*	n.s.	flotation	60
Smiths Falls	1	0.9*	−2.4 mm; −420 μm	crushing, screening, grinding, flotation	61
Timmins area	1	2	+300 μm; +150 μm; +100 μm; −100 μm	grinding, flotation, wet and dry screening	62
British Columbia					
South Bentinck	1	n.s.	+850 mm; −150 mm	screening, flotation	63

Table 5. Summary of beneficiation studies of graphite: analytical data

Deposit location	Sample No.	Head %C	Concentrate		Process methods for optimum results	Reference
			Grade %C	Recovery %		
Labrador						
Wabush	1	41.8	–	74.3	flotation, regrinding, reflotation	36
		–	81.5	–	screened –150 +70 μm	
New Brunswick						
St. John area	2	32.2	65.5	97.9	flotation	37
		–	69.8	84.4	flotation, tabling	
St. John area	1	14.0	29.0	20.7	flotation	38
Quebec						
Buckingham	1	3.3	54.5	–	flotation of +180 μm fraction	39
		–	21.6	–	flotation of –180 μm fraction	
Buckingham	1	15.6	84.5	88.4	combined tabling and flotation	40
			87.0	48.9	screened +210 μm fraction	
Guenette	1	16.3	85.8	68.4	tabling, flotation	41
			89.0	36.5	screened +210 μm fraction	
Lochaber	1	23.5	62.5	97.5	flotation, sizing	42
		–	84.5	–	screened +210 μm fraction	
Lochaber	1	21.2	60.1	90.4	flotation, sizing	43
		–	87.2	–	screened +210 μm fraction	
Buckingham	1	20.8	80.7	62.4	flotation	44
		–	93.6	–	screened +210 μm fraction	
		–	89.7	–	screened –210 +125 μm fraction	
		–	85.2	42.4	tabling, flotation	
Wentworth	1	3.4	82.8	27.8	screening of –3.4 +1.2 mm	45
Low	1	53.5	78.0	–	flotation,	46
		–	94.0	–	regrinding, reflotation	
	2	3.1	72.4	–	flotation,	
		–	95.8	–	regrinding, reflotation	
Temiskaming	1	8.4	92.0	97.7	grinding, flotation (–210 μm)	47
Bonthellier	1	68.0	96.5	95.0	flotation (–600 μm)	48
Dun Raven	1	6.0	83.7	–	vanning	49
		–	63.8	–	tabling (–1.7 mm +600 μm)	
		–	86.2	83.6	flotation (–850 +600 μm)	

Table 5. (Cont'd)

Deposit location	Sample No.	Head %C	Concentrate		Process methods for optimum results	Reference
			Grade %C	Recovery %		
Quebec (Cont'd)						
Mont Laurier	1	22.7	85.0	–	ball milling (–2.4 mm +75 μm)	50
		–	97.0	64.4	flotation, regrinding, reflotation	
		–	91.2	93.8	flotation, screening	
Gatineau	1	7.8	92.0	92.0	flotation, regrinding, reflotation	51
Mont Laurier	1	17.4	78.4	–	air tabling	52
		–	86.6	72.1	flotation (–2.4 mm)	
		–	95.4	–	flotation (–600 +210 μm)	
Ontario						
Griffith	1	34.1	75.4	99.4	flotation	53
		–	>95.0	–	screened +300 μm fraction	
Fort Frances	2	17.0	64.2	52.8	flotation	54
		–	79.5	35.9	flotation, tabling (–420 to –70 μm)	
	3	27.2	55.9	59.5	flotation	
		–	71.1	43.1	flotation, tabling (–420 to –70 μm)	
Lyndoch	1	17.2	77.5	94.2	flotation	55
		–	95.0	–	flotation, leaching	
Bancroft	1	3.4	87.7	83.9	flotation	56
	3	5.3	90.7	86.4	flotation	
Lyndoch	1	5.9	86.3	92.4	flotation	57
Lyndoch	1	6.3	95.1	91.7	flotation	58
Perth	1	11.7	98.1	–	differential grinding +210 μm	59
		–	93.5	63.3	flotation (–45 μm removed)	
Niagara Falls	1	10.0	55.4	76.0	flotation	60
Smiths Falls	1	14.9	82.5	80.6	flotation, regrinding, reflotation	61
		–	>92.0	–	flotation (+180 μm)	
Timmins area	1	5.2	97.0	79.9	flotation, regrinding, reflotation	62
		–	98.4	–	screened +300 μm fraction	
British Columbia						
South Bentinck	1	17.4	61.8	–	flotation	63

Extended firing times are sometimes required (51), and if hydrous silicate minerals such as chlorite are present, the loss of water of crystallization has to be allowed for in the analysis determination. When these minerals are present, an accurate analysis is only possible by mineralogical techniques. It is also very difficult to distinguish between graphite and free biotite.

Mineralogy

Graphite occurred as fine to coarse flakes, in schists or siliceous granitized crystalline limestone. A typical graphitic schist, as indicated by the sample from the Dun Raven mines, Quebec (49) contained 66% quartz, 12% biotite, 9% feldspar with minor pyrite, magnetite, sillimanite, rutile and apatite. In other graphitic schists, biotite was replaced by muscovite (63).

Extensive weathering was noted for several samples. Severe weathering produced a porous structure, and the associated iron oxides were oxidized to limonite as with samples from Lochaber and Buckingham, Quebec (42–44). The Mont Laurier sample, which exhibited severe weathering, was associated with quartz, diopside, goethite, sphene and apatite (50).

The mineral principally occurring with graphite, in most samples, was siliceous crystalline limestone. A wide variety of associated minor minerals including feldspar, quartz, diopside, pyroxene, sphene, apatite, clinohumite (a fluorosilicate mineral), dolomite, calcite, muscovite, phlogopite, chlorite, epidote, iron oxide minerals, pyrite, pyrrhotite and miscellaneous alumino-silicates were also reported.

Beneficiation

Crushing and screening

The beneficiation of the various graphite ores closely mirrored plant practice. The occurrence in some samples of coarse flake necessitated the evaluation of various crushing techniques to establish which technique would best preserve a coarse size flake, consistent with liberation from associated gangue minerals. Thus, ore from Mont Laurier, Quebec, was jaw crushed to between 25 and 50 mm, and secondary comminution to about 1.2 mm was assessed using a rolls crusher, Victoria mill, Hammer mill, Raymond wizzer pulverizer and a ball mill. Ball milling produced the coarsest 1.2 mm flake consistent with gangue liberation (50). Autogeneous grinding of the plus 75 mm, and minus 25 plus 2.4 mm fractions of a less weathered sample from Mont Laurier successfully separated graphite from mica with minimum flake breakage (52). A comminution study of ore from Gatineau, Quebec, compared impact crushing alone, with combined impact and rolls crushing to produce 4.8 mm flake. Screened products from each method were passed over an air table to determine which method produced the highest grade. Impact crushing produced a higher grade at 80% C (51).

An alternative method for the production of coarse flake was careful stage crushing using the same techniques with screening to remove various sized products of differing grades. Ore from Wentworth

Twp., Quebec, was stage-crushed at 3.4 mm, 1.2 mm and 600 µm. The minus 3.4 plus 1.2 mm fraction produced the highest grade at 82.8% C (45).

Tabling and screening

The production of intermediate size flake graphite was accomplished by a combination of screening and tabling. Thus, the minus 1.7 mm plus 600 µm fraction of a sample of ore from the Dun Raven Mines, Quebec, was tabled to produce a product analyzing 63.8% C (49). A sample of ore from Buckingham, Quebec, was similarly processed by grinding to 710 µm, and tabling the plus 710 µm fraction produced an intermediate size product analyzing 87.0% C (40). Re-tabling the screened plus 710 µm table concentrates obtained from Guenette, Quebec, ore increased the grade from 57.5 to 91.1% C (41).

Tabling, flotation and screening

The production of high-grade graphite from some ores was only possible by tabling at coarse sizes, and flotation at fine sizes. Fine-size graphite flotation concentrates were upgraded by removal of the very fine size fractions.

Flotation and tabling

In some instances, flotation of relatively coarse ores was followed by tabling, which increased graphite grade by rejecting gangue minerals that had floated due to smearing by graphite. Regrinding of table concentrates and reflotation was the final beneficiation stage.

The combination of flotation and tabling was used to concentrate ore from the St. John area of New Brunswick (37), from Guenette, Quebec (41), from Buckingham Twp., Quebec (40, 44), and from Fort Frances, Ontario (54). The most impressive increase in grade was with the Fort Frances ore which showed an increase from 64.2 to 79.5% C.

Flotation

Graphite is a naturally floatable mineral and coarse-size flakes up to 2.4 mm were recovered by flotation (52); the usual upper size limit was 1.7 mm (46). Flotation recovery of graphite was possible at all sizes down to 100 µm.

Flotation was successful in concentrating several low-grade ores to >85% C. An ore from Bancroft, Ontario (56) was concentrated from 5.3 to 90.7% C which represented a ratio of concentration of about 17:1. Ore from Lyndoch, Ontario (58) was similarly concentrated from 6.3 to 95.1% C which represented a ratio of concentration of about 15:1. The recovery of graphite from each of these ores was also high at 83.9 and 91.7% respectively. A high grade, 92.0% C, and a high recovery, 97.7%, were obtained on 8.4% C head grade ore from Temiskaming, Quebec (47).

Graphite is always floated by the direct method because of its natural floatability. Pine oil and kerosene are the standard collectors and are usually employed together, although cresylic acid was

used in one study (44) and methyl amyl alcohol in another (55). The alcohol frother is the primary collector, and the function of kerosene or fuel oil is as a promoter to recover unliberated graphite middlings. Pine oil additions varied from 13 to 650 g/t and kerosene from 18 to 1750 g/t. Flotation was fairly fast at 4 to 5 min, pulp density between 12 to 22% solids, the pH slightly alkaline at 8.8 to 8.9, and multiple cleaning was necessary to ensure high-grade concentrates.

Modifiers and depressants employed included sodium silicate, which acted as a quartz depressant and slime dispersant, and lactic acid, $C_3H_6O_3$, which was used to depress mica.

A summary of the principal parameter data for graphite flotation is reported in Table 6, and a summary of reagent concentration data is reported in Table 7.

Flotation and screening

The combination of flotation and screening was more effective in increasing grade. A flotation concentrate produced from Lochaber, Quebec ore analyzed 60.1% C; the plus 210 μm fraction after removal of the minus 210 μm fraction analyzed 87.2% C (43). Sizing to separate the plus 210 μm fraction of the flotation concentrate obtained with ore from Buckingham, Quebec, increased the grade from 80.7 to 93.6% C (44). An ore from Griffith, Ontario was further upgraded after flotation from 75.4 to >95% C by screening to recover the plus 300 μm fraction (53). Ore from Mont Laurier, Quebec was also similarly upgraded after flotation, from 86.6 to 95.4% C by screening to recover the minus 600 plus 210 μm fraction (52).

Regrinding

The effect of regrinding in producing high-grade graphite was particularly effective. A coarse 1.7 mm rougher flotation concentrate obtained with ore from Low, Quebec, after regrinding, was concentrated to 95.8% C (46). A gneissic graphite ore from the Timmins area, Ontario was upgraded by a combination of regrinding a rougher concentrate followed by cleaning and screening. The plus 300 μm fraction analyzed 98.4% C (62).

Ores from the Perth area, Ontario (59), and the Smiths Falls area, Ontario (61) were concentrated to >90% C by regrinding, followed by screening to remove the fine size fractions.

Miscellaneous techniques

Graphite was concentrated by a variety of miscellaneous techniques. Magnetic separation was employed to reject magnetite and biotite from the Dun Raven Mine, Quebec ore (49). Iron oxide minerals were also rejected from a graphite concentrate of Mont Laurier ore by magnetic separation (52).

Electrostatic separation was used unsuccessfully to concentrate graphite in the ore sample from Gatineau, Quebec (51). Differential grinding was successful in concentrating graphite; the plus 210 μm fraction of a differential ground ore from Perth, Ontario, analyzed 98.1% C (59). Acid leaching increased the grade of concentrated Lyndoch, Ontario, ore from 70.6 to 95% C (55).

Table 6. Summary of parameter data for graphite flotation

Deposit location	Grind size (μm)	Rough float (min)	No. of cleaner stages	pH	Pulp density % S	Reference
Labrador						
Wabush	500	11	2	8.0	20	36
New Brunswick						
St. John area	n.s.	5	2	–	–	37
St. John area	150	–	2	–	–	38
Quebec						
Guenette	-710	–	3	–	–	41
Buckingham Twp.	75% -75	–	2	–	–	44
Low	-1700	–	4	–	–	46
Temiskaming	-210	–	2	–	–	47
Bonthellier Twp.	1200	4	2	8.8	–	48
Dun Raven Mines	-1700 +600	–	3	–	–	49
Mont Laurier	-1200 +75	–	1	–	–	50
Mont Laurier	80% -300	–	4*	–	–	50
Gatineau	-1200	–	2*	–	–	51
Mont Laurier	-2400	–	4	–	–	52
Ontario						
Griffith Twp.	-600	–	2	–	–	53
Fort Frances	-600	10	2*	–	12	54
Fort Frances	-600	–	3*	–	22	54
Lyndoch Twp.	n.a.	–	–	–	–	55
Bancroft	54% -75	4	2	9.5	–	56
Lyndoch Twp.	-300	5	3	9.9	–	57
Lyndoch Twp.	77% -75	5	3	9.3	–	58
Smiths Falls	-420	–	2*	–	–	61
Timmins area	-600	6	2	8.0	20	62
British Columbia						
South Bentinck	-150	–	1	–	–	63

n.s. – not stated
n.a. – not applicable
*Rgh conc. reground

Table 7. Summary of reagent concentration data for graphite rougher flotation

Deposit location	Kerosene g/t	Pine Oil g/t	Na_2SiO_3 g/t	NaOH g/t	Lactic acid g/t	Reference
Labrador						
Wabush	18	80	–	1000*	–	36
New Brunswick						
St. John area	155	210	–	–	–	37
St. John area	1750	650	250	–	–	38
Quebec						
Guenette	185	175	–	–	–	41
Buckingham Twp.	400**	–	1000	–	–	44
Low	n.s.	n.s.	n.s.	–	–	46
Temiskaming	500	25	250	–	–	47
Bonthellier Twp.	600	35	300	–	25	48
Dun Raven Mines	n.s.	n.s.	n.s.	–	n.s.	49
Mont Laurier	185	185	–	1350	–	50
Mont Laurier	135	280	–	255	–	50
Gatineau	–	300	–	–	–	51
Mont Laurier	–	200	–	–	–	52
Ontario						
Griffith Twp.	400	n.s.	–	–	–	53
Fort Frances	240	125	–	–	–	54
Fort Frances	240	60	–	–	–	54
Lyndoch Twp.	38***	13	–	–	–	55
Bancroft	500	20	200	–	100	56
Lyndoch Twp.	650	25	250	–	–	57
Lyndoch Twp.	650	25	250	–	–	58
Niagara Falls	850	500	–	–	–	60
Smiths Falls	200	400	–	–	–	61
Timmins area	100	80	–	800**	–	62
British Columbia						
South Bentinck	–	300	250	–	–	63

n.s. – not stated

* Sodium carbonate
** Includes 150 g/t cresylic acid
*** Includes 13 g/t methyl amyl alcohol

Table 7. (Cont'd)

Deposit location	Kerosene g/t	Pine Oil g/t	Na_2SiO_3 g/t	NaOH g/t	Lactic Acid g/t	Reference
Labrador						
Wabush	72	36	–	500*	–	36
New Brunswick						
St. John area	–	210	–	–	–	37
St. John area	–	–	–	–	–	38
Quebec						
Guenette	105	55	–	–	–	41
Buckingham Twp.	–	–	500	–	–	44
Temiskaming	–	–	400	–	–	47
Bonthellier Twp.	–	10	600	–	50	48
Mont Laurier	500	510	–	3650	–	50
Gatineau	–	100	–	–	–	51
Mont Laurier	–	200	–	–	–	52
Ontario						
Fort Frances	–	–	2000	–	–	54
Bancroft	–	–	400	–	150	56
Lyndoch Twp.	–	–	750	–	175	57
Lyndoch Twp.	–	–	750	–	175	58
Smiths Falls	–	200	–	–	–	61
Timmins area	–	40	–	–	–	62

*Sodium Carbonate

CONCLUDING REMARKS

This report is the sixth in a Summary Report series on industrial minerals. It is hoped that the information presented in these and subsequent reports will be useful to all who are interested in industrial minerals in Canada.

A wide distribution of the Summary Report series is planned as a means of encouraging interest in the further development of industrial minerals for use in many diverse applications, e.g., fillers for everyday products such as paint and rubber and, in the high-technology sector, for products such as high-performance plastics, silicon chips and fibre-optic filaments.

The authors encourage feedback from reports in this series. Comments and suggestions for further R&D will be invaluable to CANMET and associated government and industry groups in further planning and conducting research on industrial minerals.

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APPENDIX A

SUMMARIES OF CANMET GRAPHITE STUDIES

LABRADOR

Identification	:	**Lab. - 1 (Ref. No. 36)***
Report - Title	:	PRELIMINARY TESTING OF A GRAPHITE SAMPLE FROM THE WABUSH AREA
- Author	:	J.M. Lamothe
- No. and Date	:	*Division Report* 89-32 (CR) 1989
Sample Description	:	Six small amorphous graphite samples each weighing 2-3 kg; the composite head analysis was 41.8% C. Associated impurities included quartz, mica and carbonaceous material.
Objective	:	To produce high-grade graphite suitable for brake lining applications.
Processing	:	Stage jaw crushing to 6 mm followed by rod milling to 500 µm. Rougher flotation followed by wet and dry screening at 300 µm and 150 µm to produce plus 300 µm and minus 300 µm plus 150 µm fractions. The minus 150 µm fraction was further cleaned by flotation, the cleaner concentrate reground, recleaned, and wet and dry sized at 70 µm and 45 µm.
Results	:	The overall graphite recovery was fair at 74.3%, but only the minus 150 µm plus 70 µm fraction was greater than 80% C at 81.5% C. Very little coarse 300 µm flake graphite was recovered.
Potential Use	:	The grade is too low grade for specialized uses, but may be suitable for certain filler applications.

*CANMET identification with reference number in brackets.

NEW BRUNSWICK

Identification	:	**N.B. - 1 (Ref. No. 37)***
Report - Title	:	CONCENTRATION OF GRAPHITE FROM ST. JOHN AREA, N.B.
- Author	:	R.K. Carnochan
- No. and Date	:	*Ore Dressing Investigation Report* (unnumbered) 1934
Sample Description	:	Sample 1, weight not stated and analyzing 35.4% C. Sample 2, weighing 136 kg analyzing 32.2% C. Graphite in both samples was amorphous and homogeneously intermixed with gangue minerals.
Objective	:	To produce high-grade graphite.
Processing	:	Crushing to 840 μm, grinding, flotation and tabling.
Results	:	The best results were obtained with Sample No. 2. Flotation produced a concentrate analyzing 65.5% C with a recovery of 97.9%. Flotation followed by tabling produced a concentrate analyzing 69.8% C with a recovery of 84.4%.
Potential Use	:	Possible use as low-grade filler material.

Identification	:	**N.B. - 2 (Ref. No. 38)**
Report - Title	:	LABORATORY BATCH FLOTATION OF GRAPHITE SAMPLE FROM ST. JOHN AREA, N.B.
- Author	:	R.A. Wyman
- No. and Date	:	*Industrial Mineral Report* 362, 1955
Sample Description	:	Finely divided graphite in a schist matrix analyzing 14% C.
Objective	:	To produce high-grade graphite.
Processing	:	Grinding to 150 μm, flotation.
Results	:	Flotation was unsuccessful in concentrating graphite as a concentrate analyzing only 29% C with a recovery of 43.4% was obtained.
Potential Use	:	Too low grade for most uses.

QUEBEC

Identification	:	**Que. - 1** (Ref. No. 39)
Report - Title	:	THE FLOTATION OF GRAPHITE TAILINGS FROM DOMINION MINE, BUCKINGHAM
- Author	:	R.K. Carnochan
- No. and Date	:	*Ore Dressing Investigation Report* (unnumbered) 1927.
Sample Description	:	4.5 t of graphite tailing containing fine-ground graphite flake, analyzing 3.3% C.
Objective	:	To produce high-grade graphite.
Processing	:	Pilot-scale flotation.
Results	:	Two concentrates were produced; plus 180 μm analyzing 54.5% C and minus 180 μm analyzing 21.6% C.
Potential Use	:	Too low grade for most commercial uses.

Identification	:	**Que. – 2** (Ref. No. 40)
Report – Title	:	THE CONCENTRATION OF A GRAPHITE ORE FROM BUCKINGHAM
– Authors	:	R.K. Carnochan and C.S. Parsons
– No. and Date	:	*Ore Dressing Investigation Report* 314, 1929
Sample Description	:	16.9 t of graphite ore analyzing 15.6% C containing flake graphite varying in size from 2.5 mm to very fine dust. Associated gangue minerals were pyrite, calcite, mica, pyroxene and other silicates.
Objective	:	To produce graphite suitable for crucible manufacture.
Processing	:	Crushing to 25 mm, followed by pilot-plant scale grinding and screening at 710 µm. The plus 710 µm coarse graphite flake was concentrated by tabling, and the minus 710 µm graphite was recovered by flotation.
Results	:	A combined table and flotation concentrate analyzed 84.5% C and represented a recovery of 88.4%.
Potential Use	:	Suitable for crucible manufacture.

Identification	:	**Que. - 3 (Ref. No. 41)**
Report - Title	:	THE CONCENTRATION OF A GRAPHITE ORE FROM GUENETTE
- Authors	:	R.K. Carnochan and C.S. Parsons
- No. and Date	:	*Ore Dressing Investigation Report* 315, 1929
Sample Description	:	12.8 t of graphite ore analyzing 16.3% C containing flake graphite varying in size from 2.5 mm to very fine dust associated with a siliceous gangue.
Objective	:	To produce graphite suitable for crucible manufacture.
Processing	:	Crushing to 25 mm followed by grinding and screening at 710 μm. The plus 710 μm coarse flake graphite was concentrated by tabling, and the minus 710 μm graphite was recovered by flotation.
Results	:	A combined table and flotation concentrate analyzed 83.5% C representing a recovery of 70.67%.
Potential Use	:	Suitable for crucible manufacture.
Remarks	:	The low recovery did not take into account graphite in middlings and cleaner tailings products which when recirculated would increase recovery. Rod milling was less destructive than ball milling to coarse flake.

Identification	:	Que. - 4 (Ref. No. 42)
Report - Title	:	GRAPHITE ORE FROM LOCHABER TWP.
- Author	:	W.S. Jenkins
- No. and Date	:	*Ore Dressing Investigation Report* 1084, 1941
Sample Description	:	24 kg of much-weathered porous graphite ore analyzing 23.5% C with associated limonite.
Objective	:	To produce graphite for commercial use.
Processing	:	Flotation and sizing at 210 µm, 125 µm and 100 µm.
Results	:	Flotation produced a concentrate analyzing 62.5% C with a recovery of 97.46%. The plus 210 µm fraction was the only fraction where graphite was upgraded above 62.50% C, to 84.51% C.
Potential Use	:	Not determined.
Remarks	:	The ore was too weathered.

Identification	:	**Que. - 5 (Ref. No. 43)**
Report - Title	:	GRAPHITE ORE FROM LOCHABER TWP.
- Author	:	W.S. Jenkins
- No. and Date	:	*Ore Dressing Investigation Report* 1085, 1941
Sample Description	:	9 kg of oxidized grey graphitic schist analyzing 21.2% C with associated iron oxides.
Objective	:	To produce graphite for commercial use.
Processing	:	Flotation and sizing at 210 μm, 125 μm and 100 μm.
Results	:	Flotation produced a concentrate analyzing 60.13% C with a recovery of 90.38%. The plus 210 μm fraction was the only fraction where graphite was upgraded above 60.13% C, to 87.16% C.
Potential Use	:	Not determined.
Remarks	:	Ore obtained from below the oxidized zone would be more representative.

Identification	:	**Que. – 6** (Ref. No. 44)
Report – Title	:	PRELIMINARY FLOTATION TESTS ON A GRAPHITE ORE FROM BUCKINGHAM TWP.
– Author	:	W.S. Jenkins
– No. and Date	:	*Ore Dressing Investigation Report* 1248, 1942
Sample Description	:	32 kg of weathered surface material containing disseminated graphite analyzing 20.8% C with associated staining by iron oxides.
Objective	:	To produce graphite for commercial use.
Processing	:	Flotation, tabling and sizing at 210 μm and 125 μm.
Results	:	Flotation produced a concentrate analyzing 80.7% C with a recovery of 62.4%. Tabling further improved the grade to 85.2% C. Sizing increased the grade in the plus 210 μm fraction to between 92.9 and 93.6% C, and in the minus 210 plus 125 μm fraction to between 84.7 and 89.7% C.
Potential Use	:	Not determined.
Remarks	:	The sample was too weathered and oxidized.

Identification	:	**Que. – 7 (Ref. No. 45)**
Report – Title	:	REPORT ON GRAPHITE FROM WENTWORTH TWP.
– Author	:	W.T. Turrall
– No. and Date	:	*Ore Dressing Investigation Report* 4210, 1942
Sample Description	:	coarse–grained siliceous limestone containing coarse–flaked graphite. Associated gangue minerals including feldspar, quartz, dolomite and diopside.
Objective	:	To produce flake graphite with a minimum 85% C content.
Processing	:	Stage crushing and screening at the following sizes; plus 3.4 mm, minus 3.4 mm plus 1.2 mm and minus 1.2 mm plus 600 μm.
Results	:	The highest grade produced was 82.81% C in the minus 3.4 mm plus 1.2 mm fraction.
Potential Use	:	Not suitable as flake graphite.

Identification	:	**Que. - 8 (Ref. No. 46)**
Report - Title	:	THE CONCENTRATION OF A GRAPHITE ORE FROM LOW
- Author	:	F.K. McK
- No. and Date	:	*Ore Dressing Investigation Report* 2281, 1947
Sample Description	:	Lot 1. 36 kg of intermixed plumbago ore and limestone, analyzing 53.52% C, associated with mica and other gangue minerals. Lot 2. 23 kg of flake graphite ore analyzing 3.00% C, associated with siliceous gangue.
Objective	:	Not stated.
Processing	:	Crushing to 6 mm; grinding to 1.7 mm and flotation. Rougher concentrate ground in a Venturi air jet to liberate gangue before cleaner flotation.
Results	:	Lot 1. A concentrate analyzing 77.99% C with a 94.00% recovery was obtained. Lot 2. A concentrate analyzing 72.42% C with a 95.82% recovery was obtained.
Potential Use	:	Not determined.

Identification	:	**Que. – 9 (Ref. No. 47)**
Report – Title	:	THE CONCENTRATION OF GRAPHITIC ORE FROM TEMISKAMING
– Author	:	H.L. Beer
– No. and Date	:	*Ore Dressing Investigation Report* (not numbered) 1952
Sample Description	:	11 kg of siliceous graphitic ore analyzing 8.4% C.
Objective	:	To produce high-grade graphite.
Processing	:	Dry grinding to 210 μm and flotation.
Results	:	A concentrate analyzing 91.98% C with a recovery of 97.7% was obtained.
Potential Use	:	The grade was high enough for certain filler applications.

Identification	:	**Que. – 10 (Ref. No. 48)**
Report – Title	:	CONCENTRATION TESTS ON A GRAPHITE ORE FROM LABELLE CNTY.
– Author	:	H.L. Beer
– No. and Date	:	*Industrial Minerals Report* 256, 1954
Sample Description	:	59 kg of graphitic ore analyzing 67.97% C, associated with silica and minor alumino–silicates.
Objective	:	To produce high–grade graphite.
Processing	:	Grinding to 1.2 mm followed by either flotation alone or tabling in conjunction with flotation.
Results	:	Flotation alone produced the best results where a concentrate analyzing 96.5% C with a recovery of 95% was obtained.
Potential Use	:	Suitable for applications requiring high–grade graphite.

Identification	:	**Que. - 11 (Ref. No. 49)**
Report - Title	:	CONCENTRATION OF GRAPHITE-BEARING SCHIST FROM DUN RAVEN MINES
- Author	:	R.A. Wyman
- No. and Date	:	*Industrial Minerals Report* 440, 1956
Sample Description	:	91 kg of graphitic schist analyzing 6.0% C associated with 66% quartz, 12% biotite, 9% feldspar and minor pyrite, magnetite, sillimanite, rutile and apatite.
Objective	:	Not stated.
Processing	:	Crushing to 1.7 mm and screening at 600 µm to produce a minus 1.7 mm plus 600 µm fraction. Vanning of the plus 1.7 mm and minus 1.7 mm plus 600 µm fractions. Magnetic separation of the minus 1.7 mm plus 850 µm and minus 1.7 mm plus 600 µm fractions. Tabling of the minus 1.7 mm plus 600 µm fractions. Flotation of the minus 1.7 mm plus 600 µm fractions.
Results	:	Vanning of the plus 1.7 mm fraction produced a concentrate with a grade of 83.7%; tabling produced a concentrate from the minus 1.7 mm plus 600 µm fraction analyzing 63.8% C. Flotation of the minus 1.7 mm plus 650 µm fraction produced a concentrate analyzing 86.2% C.
Potential Use	:	Not determined.

Identification	:	Que. - 12 (Ref. No. 50)
Report - Title	:	INVESTIGATION OF CONCENTRATION OF GRAPHITE FROM MONT LAURIER
- Author	:	W.J.D. Stone
- No. and Date	:	*Investigation Report* 58-23
Sample Description	:	Severely weathered graphite ore analyzing 22.7% C and associated with quartz, diopside, goethite, sphene and apatite.
Objective	:	To produce high-grade graphite.
Processing	:	Crushing to 25 mm to 50 mm; comparison of various comminution techniques - rolls, Victoria mill, hammer mill, Raymond pulverizor and ball mill to determine which method produces the coarsest 1.2 mm flake. Further beneficiation was by flotation of the minus 1.2 mm plus 75 μm fraction.
Results	:	Ball milling best produces coarse flake and liberates gangue minerals without adversely reducing flake size. The best grade graphite concentrate produced by flotation was 97% C with a recovery of 64.4%; the best recovery was 93.8% for a grade of 91.2% C.
Potential Use	:	Suitable for most applications requiring high-grade graphite.

Identification	:	**Que. - 13 (Ref. No. 51)**
Report - Title	:	BENEFICIATION OF GRAPHITE FROM GATINEAU
- Author	:	F.H. Hartman
- No. and Date	:	*Investigation Report* 66-79
Sample Description	:	360 kg of 15 to 18 mm lump material analyzing 7 to 8.5% C, associated with major diopside and minor feldspar, sphene, calcite, mica and clinohumite- a fluorine silicate.
Objective	:	To produce crucible-grade graphite.
Processing	:	Crushing to 25 mm, further reduction to 4.8 mm was by *a)* hammer mill alone and *b)* hammer mill in conjunction with a rolls crusher. Screened products from each comminution method were passed over an air table to determine which was the better method for concentrating graphite. Electrostatic separation and flotation were also used to beneficiate graphite. Flotation involved production of a rougher concentrate from which the high grade plus 1.2 mm and minus 1.2 mm plus 600 µm products were separated by screening. The rougher tails were reground and refloated; the graphite scavenger concentrate was then combined with the minus 600 µm rougher concentrate; the combined product was reground, refloated and recleaned.
Results	:	A combined plus 600 µm and minus 600 µm flotation concentrate analyzed 92.02% C with a recovery of 92%. The other methods of beneficiation were not effective in concentrating graphite.
Potential Use	:	Grade and size distribution indicate crucible-grade graphite.

Identification	:	**Que. - 14 (Ref. No. 52)**
Report - Title	:	BENEFICIATION OF GRAPHITE FROM MONT LAURIER
- Authors	:	F.H. Hartman and R.A. Wyman
- No. and Date	:	*Investigation Report* 74-44
Sample Description	:	136 kg of siliceous graphite ore analyzing about 15% C associated with calcite and quartz with minor mica and iron oxide minerals.
Objective	:	To produce high-grade graphite.
Processing	:	Self-grinding of plus 75 mm and minus 25 mm plus 2.4 mm material; magnetic separation of minus 600 µm material; air-tabling of minus 1.2 mm plus 150 µm. Flotation was conducted on unground minus 2.4 mm and ground minus 2.4 mm material with final upgrading by magnetic separation and screening to remove minus 210 µm fines.
Results	:	Self-grinding was successful in separating graphite from mica with minimum flake breakage. Air-tabling produced a concentrate grading 78.43% C. Flotation of unground feed resulted in a product, after screening at 210 µm, analyzing 95.4% C. Flotation of ground feed resulted in a product, after screening at 210 µm, analyzing 93.5% C; recoveries, however, were low.
Potential Use	:	Possible crucible-grade graphite.

ONTARIO

Identification	:	**Ont. - 1 (Ref. No. 53)**
Report - Title	:	GRAPHITE ORE FROM GRIFFITH TWP.
- Author	:	J.D. Johnson
- No. and Date	:	*Ore Dressing Investigation Report* (unnumbered) 1938
Sample Description	:	272 kg of graphitic ore analyzing 34.1% C associated with about 60% calcite and minor quartz.
Objective	:	To produce high-grade graphite.
Processing	:	Grinding to 40% minus 75 µm followed by flotation with screening of coarse 300 µm flake from the concentrate.
Results	:	A concentrate analyzing 75.42% C with a recovery of 99.41% was obtained. Screening to remove coarse 300 µm flake produced >95% C.
Potential Use	:	Suitable as a source of No. 1 flake.

Identification	:	**Ont. – 2 (Ref. No. 54)**
Report – Title	:	CONCENTRATION OF GRAPHITE ORE FROM RAINY LAKE AREA, FORT FRANCES
– Author	:	Anon.
– No. and Date	:	*Ore Dressing Investigation Report* 1232, 1942
Sample Description	:	Lot 1. 3 kg of siliceous graphite ore analyzing 17% C Lot 2. 9 kg of siliceous graphite ore analyzing 27.2% C. The graphite in each sample was fine flake and minor mica was present.
Objective	:	To produce No. 1 and No. 2 flake–size graphite.
Processing	:	Grinding to minus 300 μm, flotation followed by tabling to improve graphite grade. Screening at 210 μm and 125 μm to produce No. 1 and No. 2 flake graphite.
Results	:	Lot 1. A concentrate analyzing 55.86% C with a recovery of 59.5% was obtained. Tabling improved the grade to 71.06% C. Lot 2. A concentrate analyzing 64.15% C with a recovery of 52.8% was obtained. Tabling improved the grade to 79.53% C.
Potential Use	:	Too low grade for flake grade (82% C).

Identification	:	**Ont. - 3** (Ref. No. 55)
Report - Title	:	CONCENTRATION TESTS ON A GRAPHITE ORE FROM LYNDOCH TWP.
- Author	:	R.A. Elliot
- No. and Date	:	*Ore Dressing Investigation Report* 2496, 1948.
Sample Description	:	18 kg of dolomitic graphite ore analyzing 17.23% C associated with dolomitic limestone and mica. Graphite flakes were small.
Objective	:	To obtain crucible-grade graphite.
Processing	:	Flotation of unground 40% plus 210 μm material to produce a rougher and a scavenger concentrate.
Results	:	A combined concentrate analyzing 70.57% C with a recovery of 94.2% was obtained which, after leaching, to remove carbonaceous material analyzed 95% C.
Potential Use	:	Flake size is too small for crucible grade, but possible use for foundry facing, paints and lubricants.

Identification	:	**Ont. – 4 (Ref. No. 56)**
Report – Title	:	FLOTATION CONCENTRATION OF GRAPHITE ORE FROM BANCROFT
– Author	:	H.L. Beer
– No. and Date	:	*Ore Dressing Investigation Report* MD 2850, 1951
Sample Description	:	Lot 1. 24 kg of carbonaceous graphite ore analyzing 3.4% C associated with minor phlogopite and pyrrhotite. Lot 3. 44 kg of carbonaceous graphite ore analyzing 5.3% C associated with minor phlogopite and pyrrhotite.
Objective	:	To produce flake graphite for product evaluation.
Processing	:	Crushing to 1.2 mm; wet grinding to about 54% minus 75 μm followed by flotation.
Results	:	Flotation of Lot 1 material produced a concentrate analyzing 87.7% C for a recovery of 83.9%. Flotation of Lot 3 material produced a concentrate analyzing 90.7% C for a recovery of 86.4%.
Potential Use	:	Suitable for most graphite uses.

Identification	:	**Ont. - 5 (Ref. No. 57)**
Report - Title	:	FLOTATION CONCENTRATION OF TESTS ON A GRAPHITE ORE FROM LYNDOCH, TWP.
- Author	:	H.L. Beer
- No. and Date	:	*Industrial Minerals Report* 135, 1952
Sample Description	:	13 kg of graphitic ore analyzing 5.9% C associated with calcite, diopside and minor phlogopite mica.
Objective	:	To produce crucible-grade graphite.
Processing	:	Dry-ground to minus 300 μm followed by flotation.
Results	:	A concentrate analyzing 86.29% C with a recovery of 92.4% was obtained.
Potential Use	:	Possible crucible grade.

Identification	:	Ont. - 6 (Ref. No. 58)
Report - Title	:	ADDITIONAL FLOTATION CONCENTRATION TEST ON A GRAPHITE ORE FROM LYNDOCH TWP.
- Author	:	H.L. Beer
- No. and Date	:	*Industrial Minerals Report* 137, 1952
Sample Description	:	13 kg of graphitic ore analyzing 6.3% C associated with calcite, diopside and minor phlogopite mica.
Objective	:	To produce crucible-grade graphite.
Processing	:	Wet grinding to 77.3% minus 75 µm followed by flotation.
Results	:	A concentrate analyzing 95.08% C with a recovery of 91.7% was obtained.
Potential Use	:	Possible crucible grade.

Identification	:	**Ont. - 7 (Ref. No. 59)**
Report - Title	:	CONCENTRATION OF GRAPHITE FROM THE PERTH AREA OF ONTARIO
- Author	:	W.J.D. Stone
- No. and Date	:	*Investigation Report* 60-65
Sample Description	:	109 kg of carbonaceous graphite ore analyzing 11.7% C composed of aggregates of carbonaceous material with quartz and graphite. The associated minerals were minor chlorite, apatite, muscovite and epidote. A major portion of the graphite was less than 45 μm.
Objective	:	Not stated.
Processing	:	Crushing to 1.6 mm followed by various combinations of flotation, differential grinding and screening.
Results	:	The plus 210 μm fraction of a differential grinding test analyzed 98.1% C. Flotation produced a concentrate analyzing 93.5% C with a recovery of 63.3%, after removal of minus 45 μm material.
Potential Use	:	The high-grade graphite could be used for some applications.

Identification	:	**Ont. - 8 (Ref. No. 60)**
Report - Title	:	RECOVERY OF GRAPHITE FROM CYANAMID OF CANADA LTD., CARBONATE SLUDGE
- Authors	:	F.H. Hartman and R.A. Wyman
- No. and Date	:	*Investigation Report* 61-90
Sample Description	:	4.6 t of waste carbonate sludge consisting of very finely divided graphite with precipitated calcite. The estimated graphite content was 10%.
Objective	:	To produce marketable graphite.
Processing	:	Pilot-scale flotation.
Results	:	The best grade and recovery combination was a concentrate analyzing 55.4% C with a recovery of 76%.
Potential Use	:	Not determined.
Remarks	:	Further beneficiation to improve grade would involve acid leaching to remove calcite.

Identification	:	**Ont. - 9 (Ref. No. 61)**
Report - Title	:	GRINDING AND FLOTATION TESTS ON A GRAPHITE SAMPLE FROM SMITHS FALLS
- Author	:	R.A. Wyman
- No. and Date	:	*Mineral Processing Test Report* 62-52
Sample Description	:	0.9 t of graphitic ore analyzing 14.9% C, interlaminated with mica.
Objective	:	To produce either crucible grade or foundry facing grade graphite.
Processing	:	Crushing to 2.4 mm followed by a comparison between rod and ball milling to produce high-grade coarse graphite. Grinding to 1.2 mm followed by flotation with regrinding of the rougher concentrate in a four-stage locked test.
Results	:	Grinding followed by screening was only partially successful in concentrating graphite. Flotation produced a concentrate analyzing 82.5% C with a recovery of 80.6%. Screening of the concentrate produced high-grade graphite in the plus 100 µm fraction.
Potential Use	:	Possible crucible grade for plus 180 µm and foundry-facing grade for minus 180 µm plus 100 µm, but mica would have to be removed.

Identification	:	**Ont. - 10 (Ref. No. 62)**
Report - Title	:	PRELIMINARY TESTING ON A GRAPHITE SAMPLE FROM NORTHERN ONTARIO
- Authors	:	J.M. Lamothe and L. Morin
- No. and Date	:	*Division Report* 89-43 (CR)
Sample Description	:	A 2 kg sample of a weathered graphitic gneiss analyzing 5.2% C.
Objective	:	To produce a high-grade graphite product.
Processing	:	Stage crushing to 6 mm; stage grinding to 600 µm with flotation and screening at 300 µm to produce a plus 300 µm fraction. The minus 300 µm fraction was further ground followed by flotation and screening at 150 µm and 100 µm to produce plus 150 µm, minus 150 µm plus 100 µm, and minus 100 µm flake graphite fractions.
Results	:	A concentrate with a combined grade of 97% C and recovery of 79.9% was obtained. The highest grade individual product was 98.4% C for the plus 300 µm fraction, and 61% of recovered graphite was larger than 150 µm.
Potential Use	:	Suitable for uses requiring high-grade graphite.

BRITISH COLUMBIA

Identification	:	**B.C. - 1 (Ref. No. 63)**
Report - Title	:	LABORATORY BATCH FLOTATION OF GRAPHITE FROM SOUTH BENTINCK
- Author	:	R.A. Wyman
- No. and Date	:	*Industrial Minerals Report* 363, 1955
Sample Description	:	Mica-graphite schist, analyzing 17.4% C.
Objective	:	To produce coarse-flake graphite.
Processing	:	Screening at 850 μm to recover coarse graphite; flotation of ground 150 μm material.
Results	:	Screening was not successful in recovering coarse-flake graphite. Flotation produced a concentrate analyzing 61.8% C.
Potential Use	:	Too low-grade for most uses.

APPENDIX B

SUMMARIES OF GRAPHITE STUDIES BY OTHER ORGANIZATIONS

ONTARIO

Identification : **Ont. – 11 (Ref. No. 64)**

Report – Title : REPORT OF INVESTIGATIONS OF TIMMINS GRAPHITE, WESTPORT

– Author : W.P. Alderson

– No. and Date : Unnumbered Report, 1951

Sample Description : 150 t bulk sample of graphitic ore analyzing 9.61% C, associated with mica intergrowths.

Objective : Production of flake graphite.

Processing : Crushing, grinding, flotation and re-flotation.

Results : Typical product results were as follows:

Special	(+300 μm)	95.1% C
No. 1	(+180 μm)	94.1% C
No. 2	(+125 μm)	94.5% C
No. 3	(+75 μm)	88.0% C
No. 44	(–75 μm)	50.0% C
Flake	(+1.7 mm)	85.5% C

Mica intergrowths with graphite made it impossible to recover large flake high-grade graphite.

Potential Use : The property has little potential as a future producer of graphite; minimal ore reserves and mica intergrowths were the principal reasons.

Identification	:	**Ont. - 12** (Ref. No. 65)
Report - Title	:	REPORT OF INVESTIGATIONS ON THE NATIONAL BLACK DONALD MINES, WILBERFORCE
- Author	:	B.G. Edwards
- No. and Date	:	Unnumbered Report, 1951
Sample Description	:	100 t ore sample analyzing 4% C and a 100 kg drill core sample analyzing 2.5% C.
Processing	:	The 100 t sample was crushed, ground and floated in the Black Donald concentrator. Drill-core sample was evaluated at Lakefield Research Limited by crushing to 840 µm, screening and re-crushing of the oversize; a portion of the sample was concentrated by flotation.
Results	:	The 100 t sample generated products grading 96.6, 94.2, 66.6 and 47.8% C. The core sample concentrate was only 52.3% C.
Potential Use	:	Graphite in the ore sample was readily recovered by flotation and products were acceptable. Reserves were estimated at 1.5 Mt.

Identification	:	**Ont. - 13 (Ref. No. 66)**
Report - Title	:	REPORT ON A MILLING TEST OF KIRKHAM ORE, FROM GODFREY
- Author	:	B.G. Edwards
- No. and Date	:	Unnumbered Report, 1952
Sample Description	:	225 t of graphitic ore in a highly siliceous granitized phase of crystalline limestone, analyzing 11.2% C.
Objective	:	Evaluation of graphite property.
Processing	:	Processing at the Black Donald concentrator involved crushing, grinding and flotation.
Results	:	A concentrate analyzing 70-80% C was produced. A higher grade, 95% C, was obtained by re-grinding and re-flotation. The flake was tough and resisted grinding, so that the higher-grade was only obtained at a finer flake size.
Potential Use	:	Products tested by a number of companies were found to be generally satisfactory for refractory crucibles and foundry facings. Ore reserves estimated to 200,000 t.

Identification	:	**Ont. - 14** (Ref. No. 67)
Report - Title	:	PRELIMINARY TESTWORK ON TWO GRAPHITE SAMPLES FROM APSLEY
- Authors	:	J.W. Britton and D.M. Wyslovzil
- No. and Date	:	*Lakefield Research Report No.* 757, 1958
Sample Description	:	Two samples of amorphous graphite ore; sample 1 weighed 15 kg and analyzed 1.41% C, sample 2 weighed 1.5 kg and analyzed 5.33% C.
Objective	:	To produce high-grade graphite.
Processing	:	Stage crushing to 840 μm; each sample was then ground to an unspecified size, and concentrated by flotation.
Results	:	A cleaner concentrate obtained from sample 1 analyzed 86.42% C and represented 59.28% recovery. The second sample, after cleaning, analyzed 87.34% C and represented 74.54% recovery.
Remarks	:	Flake graphite was observed in the pit area from which the two amorphous graphite samples were obtained.
Potential Use	:	Further beneficiation would be required before considering acceptability for most graphite applications.

Identification	:	**Ont. - 15 (Ref. No. 68)**
Report - Title	:	PILOT PLANT DEVELOPMENT STUDIES ON MONT LAURIER, GRAPHITE DEPOSIT
- Authors	:	V.I. Lakshmanan, J. Melnbardis and D. Mackie
- No. and Date	:	*Preprint No. 84-361, Soc. Min. Eng. (AIME)*, 1984
Sample Description	:	A 43 t sample of weathered and unoxidized carbonaceous, gneissitic and quartzitic graphite ore analyzing 10.3% C.
Objective	:	To produce high-grade graphite.
Processing	:	Crushing to minus 200 mm followed by autogenous grinding to minus 1.7 mm; unit cell flotation of the mill discharge to produce a coarse 1.7 mm flake concentrate which was screened at 420 µm. The plus 420 µm screen fraction was tabled to produce a high grade table concentrate. The screen undersize was beneficiated by both flotation, cleaned, and the concentrate screened at 100 µm. The screen oversize was reprocessed by secondary regrinding followed by flotation.
Results	:	A combined coarse table concentrate and regrind flotation concentrate was obtained, which analyzed 90.1% C and represented 89.5% recovery.
Remarks	:	Acid leaching improved grade to 96-98% C.
Potential Use	:	Probably suitable for most applications.